Abstract

Cavity flows have received significant attention in the past five decades due to its practical applications and fundamental complex phenomena. Despite the enormous amount of research carried out on cavity flows, the physics of cavity flows has not been completely understood. In the present study, two- and three-dimensional solvers are developed using conservation element and solution element as the numerical scheme. Large eddy simulation (LES) is employed with dynamic Smagorinsky subgrid scale model to account for turbulent scales. Both the two- and three-dimensional numerical solvers are parallelized using message passing interface. The two- and three-dimensional solvers are validated with the experimental results.

Three-dimensional numerical simulation of cavity flow is performed, and the process of mass addition and removal is demonstrated using instantaneous contours. It has been observed that the addition of mass occurs when the vortex from the leading edge of cavity grows in size and convects downstream. While the process of mass removal takes place during merging and impingement of vortices at the trailing edge.

To analyze the results obtained from the numerical simulations, tools like proper orthogonal decomposition (POD), dynamic mode decomposition (DMD), frequency spectra obtained by fast Fourier transform (FFT), vorticity thickness, Reynolds shear stress, pressure drag coefficient, and Q_2 criterion are used. Due to the limited computational resources available, parametric studies are performed with two-dimensional numerical solver. Numerical simulations are performed for different length/depth (L/D) ratios, which are obtained by varying depth, to analyze the behavior of shallow and deep cavities. The dominant frequency of oscillation shows a sudden jump when there is a transition from shallow ($L/D > 1$) to deep cavity ($L/D < 1$). The first two POD and DMD spatial structures of deep cavity reveal the presence of vortex pairing analogous to mixing layer. Flow past cavities with increasing boundary layer thickness are carried out to evince the suppression of self sustained oscillations in supersonic open cavity flows. Reynolds shear stress for thin boundary layer displays features similar to free mixing layer, whereas a moderately thick boundary layer exhibits behavior similar to forced mixing layer. The first two dominating POD modes for thin boundary layer indicate flapping of entire shear layer, whereas for the thick boundary layer, they represent flapping of the lower part of shear layer. The various analysis performed to study the effects of boundary layer thickness leads to the conclusion that thickening of incoming boundary layer inhibits the growth of disturbance, which results in reduced amplitude of oscillations, and hence provides stability to the shear layer. To study the effects of variation of Mach number, computations are performed at two different Mach numbers (1.5 and 2). The Mach numbers are selected such that there exists a shift in the dominant frequency of oscillations from one Rossiter mode to another. The growth rate of shear layer for Mach number 1.5 displays two different rates, while for Mach number 2, it shows four different growth rates along the length of cavity.

Keywords: Supersonic cavity flows, compressible Navier-Stokes solver, conservation element and solution element method, LES, parallel computing, POD, DMD.